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Evolutionary Game Theoretic Perspective on Analysis of Cloud Computing Security Investment

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Abstract

This paper uses evolutionary game theory to research the security investment issue of Cloud computing. First, under the premise of the bounded rationality of Cloud users, we set up evolutionary game model of Cloud computing security investment. And then, we investigate replicator dynamics and evolutionary stable strategies of Cloud user groups. The evolutionary game results can be applied to analyze the implementing process and predict the trends of changes of game part groups, and provide decision support for Cloud users about their Cloud computing security investment.

Keywords

Cloud Computing; Security Investment; Evolutionary Game; ESS

Introduction

As cloud computing thrives, increasing enterprises and users are deploying their applications to the cloud. Cloud computing has become a new IT deployment pattern which can accelerate deployment of applications without consuming the computing resources of enterprises, and cloud users can dynamically scale the computing resources to applications as demand changes [1]. Despite those benefits, the architecture of cloud poses such a threat to the security of the existing technologies when deployed in a cloud environment [2]. The cloud is just built over the internet and all the concerns related to security in internet are also posed by the cloud. The basis of the cloud technology makes the consumer and provider reside at different location and virtually access the resources over the Internet. Even if enormous amount of security is put in place in the cloud, still the data is transmitted through the normal underlying Internet technology. So, the security concerns which are threatening the Internet also threaten the cloud [3].

Public clouds exhibit a unique type of interdependency because of the ability of an attacker to propagate his attack through the hypervisor to all VMs using the hypervisor [4]. In a dense network of clouds, an attacker may launch an indirect attack on a user's cloud-application by first compromising another user's cloud-application that is at the same hypervisor with the target application. Many users do not invest on Cloud application security due to higher investment costs and lower probability of Cloud computing security accident. This may create a risk connection among the users of a cloud where a part of cloud users who have safe applications deployed on the cloud will not use Cloud application service by reason of the risk imposed by another cloud user who does not make a security investment of their Cloud applications. That is to say that a user of a cloud cannot protect itself if other users are not doing the same. On the contrary, a user will not be suffered from Cloud security if it defends itself while other users are also making a Cloud security investment. So Cloud computing security investment is indispensable for each cloud user.

However some Cloud users may consider that the probability of Cloud application security accident attacked by an attacker is lower, these users are reluctant to invest on Cloud application security with a higher investment costs.

This yields a negative externality to other Cloud users in the Cloud, and more Cloud users will adopt 'No Investment' strategy. Eventually the probability of Cloud application security accident will become higher and the interests of all Cloud users will be jeopardized.

On account of strategy dependency of users' Cloud computing security investment, game theory can be applied to research the strategy issue of Cloud computing security investment. The players in game model of Cloud computing security investment have been assumed to have bounded rationality, so the paper uses evolutionary game theory to analyze strategy Selection of Cloud computing security investment.

This paper mainly researches strategy issue of Cloud computing security investment from the perspective of evolutionary game theory and the rest of the paper is organized as follows. Section II will present evolutionary game model of Cloud computing security investment. Section III will detail replicator dynamics and evolutionary stable strategy analysis of cloud computing security investment, and predict the long-term stability trends of Cloud computing security investment. Finally, some conclusions in this paper and further research work will be presented in Section IV.

Evolutionary Game Model of Cloud Computing Security Investment

In real world, entirely rationality does not exist. There may be a greater bounded rationality especially when dealing with complex game problems. Evolutionary game theory with bounded rationality has provided a new way to explain complicated activities in social life. Cloud computing security investment is also a very complex problem, so investment decision often depends on gut instinct behaviors or imitation of other deciders' successful strategies, rather than optimization and game model analysis. So this paper, based on the bounded rationality of investors, sets up evolutionary game model of Cloud computing security investment.

In this game mode, the two players are assumed to have bounded rationality, which means each player has not a full understanding of the game and has the ability to take the actions that maximize his expected payoff through rational analysis. A strategy is a rule for choosing which action to perform. Each player has two strategies: investment and no investment, which means they can either invest in Cloud computing security to increase their application security deployed on the Cloud or not do.

Then we can refer to some parameters as follows. B is the benefit of user, which is independent of benefit of Cloud computing security investment. C represents investment costs for Cloud computing security. L is the lost from Cloud computing security issue and the loss probability, whether users have invested Cloud computing security or not, is q_1 and the loss probability caused by other users is q_2 which represents negative externalities among the Cloud computing users, and the loss probability caused by the user himself is denoted q_3 . The last parameter I stands for intangible benefit from the security investment of Cloud computing.

TABLE I THE PAY-OFF MATRIX OF GAME MODEL OF CLOUD COMPUTING SECURITY INVESTMENT

Player1	Player2	
	Investment	No Investment
Investment	$B\text{-}C\text{-}q_1L\text{+}I$, $B\text{-}C\text{-}q_1L\text{+}I$	$B\text{-}C\text{-}q_1L\text{-}q_3L\text{+}I$, $B\text{-}q_2L$
No Investment	$B\text{-}q_2L$, $B\text{-}C\text{-}q_1L\text{-}q_3L\text{+}I$	$B\text{-}q_2L\text{-}(1\text{-}q_2)q_3L$,$B\text{-}q_2L\text{-}(1\text{-}q_2)q_3L$

Evolutionary game of Cloud computing security investment is visually represented as a payoff matrix as shown in Table 1, in which the payoff for the user involved is shown for all possible interactions. If the two players both invest Cloud computing security, the payoffs of them are $B\text{-}C\text{-}q_1L\text{+}I$. Instead, if neither of the two players invest Cloud computing security, each of them has own security risks with the probability q_3 and negative externalities caused by other users with the probability q_2 , and thus the payoffs of them are $B\text{-}q_2L\text{-}(1\text{-}q_2)q_3L$. If the strategy of player 1 is investment, and encounters that player 2 chooses 'no investment', the payoff for player 1 is $B\text{-}C\text{-}q_1L\text{-}q_3L\text{+}I$ and for player 2 is $B\text{-}q_2L$.

Replicator Dynamics and ESS Analysis of Cloud Security Investment

1) Replicator Dynamics of Evolutionary Game of Cloud Computing Security Investment

In mathematics, the replicator equation is a deterministic monotone non-linear and non-innovative game dynamic used in evolutionary game theory and can reasonably characterize the stability of bounded rationality game party through dynamic learning and adjustment [5]. The two players in game model of Cloud computing security investment have been assumed to have bounded rationality, so the replicator dynamics model can be applied to analyze the implementing process and predict the trends of changes of game part groups, and put forward for the reasonable macro control of Cloud computing security issue.

In this game model, we consider that the proportion of the players with the strategy of investing in cloud computing security is denoted x, and the proportion of no investment strategy is 1-x. we set u_1 as the expected payoffs of game party adopting investment strategy in this game model:

$$u_1 = x(B - C - q_1L + I) + (1 - x)(B - C - q_1L - q_3L + I) \quad (1)$$

u_2 is the expected payoffs of game party adopting no investment strategy in security investment model of Cloud computing:

$$u_2 = x(B - q_2L) + (1 - x)[B - q_2L - (1 - q_2)q_3L] \quad (2)$$

Thus, the overall average expected payoffs $\bar{u}$ can be deduced as follows,

$$\bar{u} = xu_1 + (1 - x)u_2 \quad (3)$$

From equation (1) to (3), we have the expression of replicator dynamics of Cloud computing security investment:

$$\frac{dx}{dt} = x(u_1 - \bar{u}) = x(1 - x) * [q_2q_3Lx + (q_1 + q_2)L + I - C - q_2q_3L] \quad (4)$$

We suppose that replicator dynamics of evolutionary game of Cloud computing security investment is equals to zero:

$$x(1 - x)[q_2q_3Lx + (q_1 + q_2)L + I - C - q_2q_3L] = 0 \quad (5)$$

So through solving this replicator dynamics equation, three stable states can be deduced as follows:

$$x_1 = \frac{C + q_2q_3L - (q_1 + q_2)L - I}{q_2q_3L}$$

$$x_2 = 0 \; and \quad x_3 = 1$$

2) Evolutionary Stable Strategy Analysis of Game Model

An evolutionarily stable strategy (ESS) is a strategy that cannot be invaded by another strategy and can be used to predict long-term stable trend of game group behavior [6]. This means that, if the proportion of adopting investment strategy is less than ESS, then the value of must be greater than 0. If x is greater than ESS, then the value of must be less than 0. So we can conclude that if satisfied, the proportion of adopting investment strategy is an evolutionary stable strategy.

Setting f(x)=dx/dt and x_1=a . According to (4), we can get

$$f(x)=dx/dt=x(1-x)(x-x_1)$$
$$=-x^3+(x_1+1)x^2-x_1x$$
$$\Rightarrow f'(x)=(dx/dt)'=-3x^2+2(x_1+1)x-x_1$$

When x =0 and x=1, the corresponding value of is – and -1 respectively as follows:

$$f'(x)=\begin{cases}-x_1 & x=0\\ x_1-1 & x=1\end{cases}$$

When x is an ESS. Thus, we can conclude whether the proportion of adopting investment strategy is an evolutionary stable strategy. Evolutionary stable strategy (ESS) depends on the value of

$$x_1=\frac{C+q_2q_3L-(q_1+q_2)L-I}{q_2q_3L}$$

so we analyze ESS of Cloud computing security investment game according to the range of values for X_1.

- Evolutionary stable strategy under given, that means. As x ranges from 0 to 1, the replicator-dynamics of Cloud computing security investment evolutionary game include two stable states with $x_2=0$ and $x_3=1$. According to formula (5) and the condition, we have $f'(0)>0$ and $f'(1)<0$, so $x_3=1$ is the unique ESS of evolutionary game of Cloud computing security investment. Because of lower investment cost of Cloud computing security, all users will be willing to adopt Cloud computing security investment strategy.

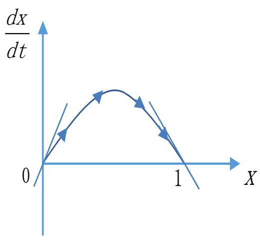

FIG 1. THE PHASE DIAGRAM OF REPLICATOR DYNAMICS EQUATION UNDER $x_1 \le 0$

- Evolutionary stable strategy under $0<x_1<1$

  Given $0<x_1<1$, that means $(q_1+q_2)L+I-q_2q_3L< C< (q_1+q_2)L+I$. In this condition, there are three stable strategies of replicator dynamics, i.e.

$$x_1=\frac{C+q_2q_3L-(q_1+q_2)L-I}{q_2q_3L}$$
$$x_2=0andx_3=1$$

According to formula (5) and the condition $0<x_1<1$, we have $f'(0)<0$ and $f'(1)<0$. As indicated in Figure 2, the phase diagram of replicator dynamics equation under $0<x_1<1$ shows that the ESSs under $0<x_1<1$ are $x_2=0$ and $x_3=1$. In this condition, if the initial proportion(x) of adopting Cloud computing security investment strategy ranges from 0 to x_1, 0 is the evolutionary stable strategy (ESS); if x ranges from x_1 to 1, 1 is ESS that means all players would adopt Cloud computing security investment strategy.

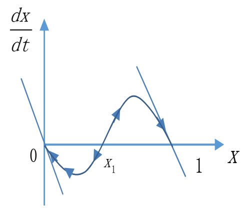

FIG 2. THE PHASE DIAGRAM OF REPLICATOR DYNAMICS EQUATION UNDER $0 < x_1 < 1$

3) Evolutionary Stable Strategy Under $x_1 \geq 1$

Given $x_1 \geq 1$, that means $C \geq (q_1+q_2)L+I$. In this condition, there are only two evolutionary stable strategies of replicator dynamics, i.e. $x_2 = 0$ and $x_3 = 1$. According to formula (5) and the condition $x_1 \geq 1$, we have $f^{'}(0)<0$ and $f^{'}(1)>0$. As indicated in Figure 3, the phase diagram of replicator dynamics equation under $x_1 \geq 1$ shows that the unique ESS under $x_1 \geq 1$ is $x_2 = 0$. In this condition, because the investment cost of Cloud computing security is higher, therefore the users are reluctant to invest in Cloud computing security during the long-term evolution. In order to reduce security risks of using Cloud computing, crucially, Cloud computing security technology must be developed to improve the safety of Cloud computing and lower the investment cost of Cloud computing security.

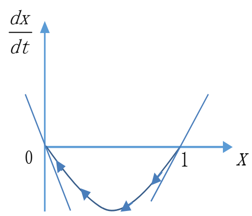

FIG 3. THE PHASE DIAGRAM OF REPLICATOR DYNAMICS EQUATION UNDER $x_1 \geq 1$

Conclusions

This paper mainly researches strategy issue of Cloud computing security investment with evolutionary game theory. Considering the bounded rationality of Cloud users in reality, we build evolutionary game model of Cloud computing security investment. And we investigate evolutionary stable strategies of Cloud user groups under three different conditions using replicator dynamics theory. The research result shows that the investment costs of Cloud computing security is crucial element for Cloud users to strategy selection and can predict the long-term trend of Cloud security investment strategy for Cloud users and provide a reference for Cloud computing security investment of Cloud users. For future work we intend to simulate this evolutionary game with simulation software to verify the evolutionary stable strategy.

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